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STORAGE FOR MUNICIPAL AND INDUSTRIAL WATER SUPPLY COPAN, SAND AVANT, AND SKIATOOK RESERVOIRS AND STREAM QUALITY CONSIDERATIONS LOWER VERDIGRIS RIVER BASIN OKLAHOMA

Public Health Service
Dallas, Texas

June 1961

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

In Cooperation with the

DEPARTMENT OF THE ARMY
U. S. Army Engineer District - Tulsa, Oklahoma

JUNE 1961

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STORAGE FOR

MUNICIPAL AND INDUSTRIAL WATER SUPPLY

COPAN, SAND, AVANT, AND SKIATOOK RESERVOIRS

AND

STREAM QUALITY CONSIDERATIONS

LOWER VERDIGRIS RIVER BASIN

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I. INTRODUCTION

General

This report is concerned with four multiple-purpose reservoirs in the lower Verdigris River basin currently being studied by the Corps of Engineers. These reservoirs are: Skiatook, on Hominy Creek; Avant, on Bird Creek; Sand, on Sand Creek; and Copan, on Caney Creek.

The original request for the investigation was contained in a letter dated June 10, 1958, from the Tulsa District, Corps of Engineers. In that letter, the District Engineer asked the Public Health Service to "...provide data on quality of water, water pollution and minimum flow requirements for pollution abatement and beneficial effects in the lower Verdigris River basin."

The scope of the study was subsequently enlarged to conform to general policy established by a Memorandum of Agreement between the Departments of the Army and Health, Education, and Welfare, dated November 4, 1958. The Memorandum established a general working arrangement between the Public Health Service and the Corps of Engineers in regard to the Water Supply Act of 1958.

As its scope has evolved, therefore, the purposes of this investigation were: to determine the present and anticipated future needs for storage in the four reservoirs to meet projected municipal and industrial water demands; to examine the waste disposal and stream quality problems incident to such water use; and to estimate the monetary values of storage for water supply and for stream quality maintenance.

A special feature of the study is the consideration of the effect of canalization of the lower Verdigris River on the stream's capacity to assimilate municipal and industrial wastes.

Acknowledgments

The cooperation and assistance of many persons and agencies are gratefully acknowledged. Special appreciation is expressed to the following:

Oklahoma State Department of Health
Oklahoma Water Resources Board
Tulsa Metropolitan Area Planning Commission
Director, Department of Water and Sewerage, Tulsa, Oklahoma
City Manager, Bartlesville, Oklahoma

II. SUMMARY AND CONCLUSIONS

Summary

1. The four reservoirs under study are located on tributaries of the lower Verdigris River in Oklahoma.

2. The area studied as potential beneficiary of water supply storage in the projects lies entirely within the State of Oklahoma, and extends from the Tulsa urban area northward to the Kansas - Oklahoma State line. Findings are reported in three parts: Subarea Number 1 centered in Bartlesville, Oklahoma; Subarea Number 3 centered in Tulsa, Oklahoma; and an intervening Subarea Number 2.

3. In addition to present sources, a major potential source of future water supply for the study area is the Oologah Reservoir, now under construction on the Verdigris River some 40 miles north of Tulsa. Secondary sources are the existing Hulah Reservoir on the upper Caney River, and the projects under study herein.

4. With continued improvement in the control by state agencies of manmade pollution sources, the quality of the water that would be stored in study projects is expected to be satisfactory, after normal treatment, for general municipal and industrial use.

5. In the year 2010, the projected municipal population of Subarea Number 1 is 110,000; corresponding water demand is estimated at 24.8 mgd (million gallons daily) for municipal and industrial use. An additional 13 mgd will be desirable to maintain sufficient flow in the Caney River at Bartlesville for assimilation of resultant wastes after secondary treatment. A reasonable plan for meeting these projected needs is the utilization of storage in Hulah, Sand and Copan Reservoirs, in that order. The existing Hulah Reservoir should be adequate until about the year 1975, after which additional sources will be needed.

6. The municipal population projected for Subarea Number 2 in 2010 is 15,000. Municipal and industrial water requirements will total about 3.0 mgd,

of which approximately half can be met from present facilities within the area. Since the population of this area is in scattered small communities, no serious waste-disposal - stream-quality problems are anticipated.

7. The greatest concentration of people and fastest rate of growth are projected for Subarea Number 3, the Tulsa urban area. By 2010, this area's projected population is 900,000. The projected municipal and industrial water demand is 239 mgd, of which present sources will be able to supply about 105 mgd. The additional demand can be supplied by Oologah Reservoir, supplemented by small contributions from the return flows in the Caney River and, possibly, by storage in Avant and Skiatook Reservoirs.

8. With respect to waste discharges and their effect on stream quality, the most critical areas will be in the Arkansas and Verdigris Rivers below Tulsa. Maintenance of stream quality will require, first of all, that all wastes be given the most complete treatment that is reasonably attainable - at least through secondary treatment. Additional measures might be: (1) low-flow augmentation in sufficient volume to assimilate all wastes after secondary treatment; (2) tertiary treatment, such as lagooning, for all or part of the residual wastes; or (3) a combination of the two.

9. The study area as a whole is blessed by nature with abundant sources of water to meet foreseeable future needs for all purposes. There will be problems in assuring dependability of supply, in preserving water quality, and in protecting streams from pollution. These problems can be solved by careful planning and cooperative effort.

Conclusions

1. In Sand Reservoir, provisions should be made for the maximum economically feasible amount of storage for municipal and industrial water supply. For a yield of 7.8 mgd, the value of storage will be $161,500 per year, from the year of first need, 1975. The annual value adjusted to the year 1965 is $109,000, or 3.8 cents per thousand gallons of yield.

2. The provision of optimum storage is also recommended in Copan Reservoir. Such storage could ultimately be utilized for water supply, and would have an interim use, from about 1990, for stream quality maintenance. For a yield of 4.0 mgd, the value of storage, from and after the year 1990, will be $115,000 per year. The annual value adjusted to the year 1965 is $43,100, or 3.0 cents per thousand gallons of yield.

3. Provision of storage in Avant Reservoir to yield about 2.0 mgd is recommended. The estimated value of this storage is $85,400 per year, or 11.7 cents per thousand gallons. This unit value applies only to the local demand, in the town of Pawhuska or areas in close proximity to the reservoir. It should not be used to extrapolate value for larger yields, since downstream demands can be supplied from other sources at considerably lower cost.

4. Storage in Skiatook Reservoir could contribute a small share toward meeting the water demands of the Tulsa area, if it can be provided at a low unit cost. For municipal and industrial water supply, storage to yield 4.0 mgd would have a value of $12,700 per year (0.87 cents per thousand gallons). For waste assimilation in the stream, storage yielding 4.0 mgd would have a value of $3,440 per year, or 0.235 cents per thousand gallons.

III. DESCRIPTION OF PROJECTS AND STUDY AREA

Location and Description

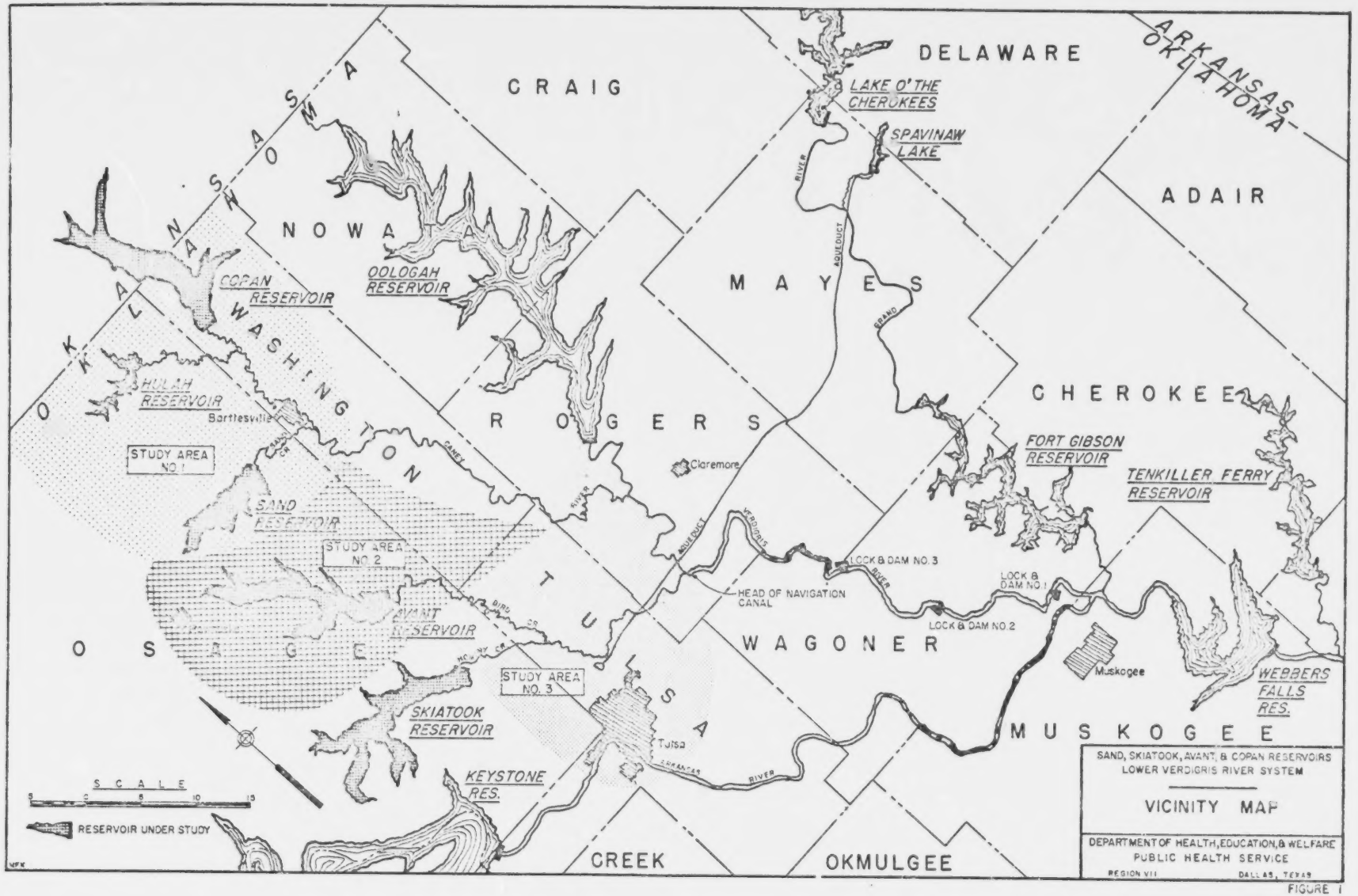
The Verdigris River is a major tributary of the Arkansas, entering that river near Muskogee, Oklahoma. It is about 340 miles long and flows in a southerly direction through Kansas and Oklahoma. Of particular interest in this report is the lower Verdigris River system. This includes the main stem from its confluence with the Arkansas River to the Oologah Reservoir at mile 90, and two principal tributaries, Caney River and Bird Creek.

Figure 1 is a map showing the general area and the locations of the four study projects in relation to other features. Preliminary pertinent data for the projects, furnished by the Corps of Engineers, are given in Table 1.

Table 1

Preliminary Pertinent Data
For Projects Under Investigation
Verdigris River Basin

Feature	Reservoir			
	Copan	Sand	Avant	Skiatook
Location:				
Stream	Caney Cr.	Sand Cr.	Bird Cr.	Hominy Cr.
River Mile	9.6	19.1	57.6	14.3
Purpose:	F.C. & C.	F.C. & C.	F.C. & C.	F.C. & C.
Drainage Area, sq. mi.	501	137	336	354
Elevations, ft., m.s.l.				
Top of Dam	742.5	804.5	762.0	707.0
Maximum Pool	738.5	799.1	756.9	701.6
Top of Pool, F.C.	732.0	782.0	747.0	695.0
Top of Pool, C.	708.0	758.5	715.0	661.5
Reservoir Area, acres				
Top of Pool, F.C.	12,600	3,100	7,230	6,660
Top of Pool, C.	3,470	1,450	1,650	2,200
Reservoir Storage, A.F.				
Flood Control	175,500	51,700	134,100	141,000
Conservation (W.S.)	12,000	21,100	10,900	10,200
Sediment	12,000	4,300	9,000	12,000
Total	199,500	77,100	154,000	163,200
Water Supply Yield, mgd	4.0	7.8	5.0	4.0



SAND, SKIATOOK, AVANT, & COPAN RESERVOIRS
LOWER VERDIGRIS RIVER SYSTEM

VICINITY MAP

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 1

These projects are being studied as part of the Arkansas River Main Control Plan although they are not major elements of the plan. A major feature of the main control plan is the provision of a navigation channel, following the Verdigris River from Catoosa (15 miles northeast of Tulsa), 52 miles downstream to the Arkansas River, thence down the Arkansas to the Mississippi River. The waterway will be canalized by a series of locks and dams.

Three low-head navigation locks and dams will be provided on the Verdigris River, with lifts ranging from eight to seventeen feet. Minimum channel depth is to be nine feet, and a channel width of 150 feet will be provided on the Verdigris River section. Bank stabilization and channel rectification works will control meandering, in times of low flow.

When the system is completed and in operation, a part of the storage in Oologah Reservoir will be used to maintain minimum stream flows required by navigation. Table 2 gives the minimum stream flows to be maintained at head-of-navigation on the Verdigris River, as projected by the Corps of Engineers.

Table 2

Navigation Stream Flows
Verdigris River at Catoosa

Month	Minimum Flow, cfs*
January	93
February	93
March	93
April	103
May	133
June	133
July	162
August	153
September	133
October	113
November	103
December	93
Annual Average	117

*Cubic feet per second

Along with its other purposes, Oologah Reservoir is planned to be a major source for municipal and industrial water supply in the future. Since Oologah Reservoir and the existing Hulah Reservoir are major elements in the water supply picture of the study area, pertinent data for these two reservoirs are given in Table 3 for future reference.

Table 3

Pertinent Data
Oologah and Hulah Reservoirs
Ultimate Development

Feature	Oologah Reservoir (ultimate development)	Hulah Reservoir
Drainage Area - sq. mi.	4,339	732
Elevation, Top of F. C. Pool	661	765
Elevation, Top of Conservation Pool	638	733
Elevation, Top of Minimum Pool	592	710
Flood Control Storage - acre-feet	965,600 a/	257,800 b/
Conservation Storage - acre-feet	544,100 c/	33,400 d/
Firm Yield, mgd	230 e/	15 f/

a/ Includes 15,600 acre-feet of sediment reserve.
b/ Includes 5,000 acre-feet of sediment reserve.
c/ Includes 33,500 acre-feet of sediment reserve.
d/ Divided as follows:
(1) Water Supply -- 19,800 acre-feet.
(2) Pollution Abatement -- 7,100 acre-feet.
(3) Sediment Reserve -- 6,500 acre-feet.
e/ 76 mgd for navigation and 154 mgd for water supply.
f/ Estimated combined yield from water supply and pollution abatement storage, after 50 years.

Quality of Water

The decision to impound surface waters for municipal and industrial use should include consideration of the expected quality of the stored water. Of particular significance are those impurities which are both objectionable and not amenable to removal or reduction by normal treatment processes.

An approximation of the stored-water quality to be expected may be obtained from a long-term record of laboratory analyses of samples taken from the stream. Ideally, samples should be taken near the reservoir site, and at sufficiently close time intervals to define the pattern of variations in quality as well as the concen-

trations of significant constituents. This ideal is approached at some locations, by the sampling program of the U. S. Geological Survey, with results published in the Water Supply Papers.

Table 4 is an abstract of significant quality data, as obtained by the U. S. Geological Survey at three of the water quality stations in the area. The complete records can be found in the original sources.1/

In general, the critical factors in the question of acceptability of surface water sources in this area are the concentrations of chlorides and total dissolved solids. The recommended maximum concentration of chlorides is 250 ppm (parts per million). For dissolved solids, the preferable maximum is 500 ppm, concentrations up to 1,000 being permissible where the higher quality is not attainable.14/

There are no major sources of natural pollution in the Verdigris River basin. A serious stream pollution problem has existed in the past because of the build up of chloride concentration due to oil field operations. Both Oklahoma and Kansas have active programs to reduce the brine pollution of streams. These programs have already shown good results, and further improvement is confidently expected. Nevertheless, a warning note is sounded by the fact that water samples continue to show high chloride content part of the time.

The impoundment and regulation of natural runoff by a storage reservoir tend to smooth out extreme variations in both quantity and quality of the water. Fortunately, the high chloride concentration usually occurs at low flows, and vice versa. An approximate indicator of the quality to be expected in a reservoir is the discharge-weighted average concentration. (This is one reason why discharge measurements should accompany a program of sampling for chemical analysis.) Judicious operation of a reservoir can also improve the quality of stored water. This can be accomplished by flushing out the reservoir in times of flood flow and capturing part of the higher-quality water. Additional assurance would be obtained by designing the outlet structure for selectivity in the elevation of the takeout point. This would counteract the tendency toward stratification of waters of different density in the reservoir.

The records in Table 4 indicate that water would be of satisfactory quality in storage projects on Bird Creek and in Oologah Reservoir on the Verdigris River.

In contrast, it will be noted that Arkansas River water is not satisfactory. Both natural and man made sources contribute to its pollution, and the Arkansas River is introduced here only to show that it is not an alternative source, even though it is the largest stream and the one most conveniently located to Tulsa.

Table 4

Chemical Analyses of Surface Waters

		Chloride (Cl) ppm	Sulfate (SO_4) ppm	Total Dissolved Solids ppm	Discharge cfs
Bird Creek near Sperry, Oklahoma					
Water Year 1952	Maximum	1,090	43	2,150	
1952	Minimum	43	10	211	
1952	Weighted Average	105	22	345	370
Water Year 1953	Maximum	1,910	32	3,590	
1953	Minimum	38	5	167	
1953	Weighted Average	109	16	314	151
Verdigris River near Claremore, Oklahoma					
Water Year 1951	Weighted Average	36	18	233	5,919
1952	Weighted Average	57	38	320	2,993
1953	Weighted Average	114	38	387	475
1954	Weighted Average	69	20	270	706
Arkansas River near Tulsa, Oklahoma					
Water Year 1951	Weighted Average	422	139	1,070	15,620
1952	Weighted Average	734	196	1,720	5,444
1953	Weighted Average	1,120	164	2,300	1,822
1954	Weighted Average	1,370	174	2,750	1,260
1955	Weighted Average	902	155	1,910	3,227

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Published water quality data for the Copan and Sand Reservoir sites are fragmentary and inconclusive. Supplementing these records are the opinions of people who have had first-hand experience with the streams. It is reported that Caney Creek has had, at times, very high concentrations of chlorides. There is some evidence of similar occurrences in Sand Creek. It seems safe to assume that this situation also is (or has been) caused by oil well operations, and can be corrected.

It is concluded that there is reasonable assurance that water stored in any of the study projects would be satisfactory for general municipal and industrial use.

Potential Water Demand Area

The area studied as potential beneficiary of water supply storage in the projects lies entirely within the State of Oklahoma, and extends from the Tulsa urban area northward to the Kansas - Oklahoma State line. It has been divided into three parts: Subarea No. 1, centered in Bartlesville, Oklahoma; Subarea No. 3, centered in Tulsa; and an intervening Subarea No. 2. Population and water demand have been projected separately for each subarea.

IV. POPULATION PROJECTIONS

Methodology

An important step in making a fifty-year projection of future municipal and industrial water requirements is a forecast of municipal population. Also needed is an indication of the pattern of industrial activity, since it affects both the supporting employment and the amount of industrial water needed.

In forecasting populations, consideration was given to the following factors:

(1) The past history and future projection of the population of the Nation as a whole.

(2) The past, present, and future growth trends of the region.

(3) The past record and present base of the particular place that is to be projected.

(4) The growth experienced by other urban centers which, fifty years ago, were of sizes comparable to the present size of the place to be projected.

(5) The economic and cultural environment - natural resources, locational advantages, transportation facilities, commerce and trade activities; and that most difficult to appraise of all factors, the human element reflected in enlightened leadership.

The general method used was to obtain all available information relevant to the five factors, to weigh the data with regard to the relative influence of each factor - and, finally, to project a population for each of the three subareas.

The Economic Environment

Statistical data have been compiled and abstracts are given herein for the tri-county area of Osage, Tulsa, and Washington Counties, Oklahoma. These are generally indicative of the economic base for the study area.

The three basic industries of the area are agriculture, mining, and manufacturing.

The role of agriculture has steadily declined in recent years, and it is now the least significant of the three activities, in the economy of the area. Recent trends in the number of farms, acreage harvested, and value of crops and livestock sold are exhibited in Table 5. All dollar figures in the table have been adjusted to the 1944 value of the dollar.

Table 5 [8/]

Agricultural Statistics for the Tri-County Area

Year	Number of Farms	Acres of Cropland Harvested	Value of Crops Sold ($1,000)	Value of Livestock Sold ($1,000)
1944	7,785	365,503	5,101	14,964
1949	5,563	233,661	3,621	12,674
1954	4,263	200,775	2,403	12,386

Although detailed statistics of the type given in Table 5 are not available for years subsequent to 1954, it is known that agricultural employment has continued to decline.

Mineral extraction (especially oil) is an important segment of the economic base of the area. Osage County in 1958 was the State's leading oil-producing county, and also ranked first in the total value of minerals produced. Comercially worked minerals throughout the tri-county area include petroleum, natural gas, stone, clay, limestone, coal, sand, and gravel.

The total value of minerals, extracted annually, more than doubled between 1952 and 1958. See Table 6.

Table 6 [11/]

Value of Mineral Production

Year	Osage County ($1,000)	Washington County ($1,000)	Tulsa County ($1,000)	Tri-County Total ($1,000)
1952	27,306	12,805	5,542	45,653
1953	32,977	15,477	5,792	54,246
1954	36,825	16,288	6,382	59,495
1955	56,223	20,002	6,524	82,749
1956	68,558	16,750	7,083	92,391
1957	81,010	18,554	7,199	106,763
1958	76,367	19,352	7,176	102,895

The major role of manufacturing, especially in Tulsa County, is shown by the figures presented in Table 7. A further indication of the importance of manufacturing to the economy of Tulsa is the increasing ratio of the number employed in manufacturing to the total labor force; from 13.7 per cent in 1940 to 17.8 per cent in 1950, and to an estimated 21 per cent in 1960. Roughly half of this employment is in resource-oriented manufacturing, such as oil refineries; the greater portion of the other half are employed in the making of aircraft and other fabricated metals.

Table 7

Value Added by Manufacturing

Year	Osage County ($1,000)	Washington County ($1,000)	Tulsa County ($1,000)	Tri-County Total ($1,000)
1954	3,158	14,786	203,125	221,069
1958	4,401	16,374	236,479	257,254

Retail and wholesale trade and all other service industries account for the largest segment of total employment - about 68 per cent in Tulsa at present. For the tri-county area as a whole, statistical data of number employed and dollar volume of trading activities have been studied. Since these studies reveal no significant departure from the norm, details are omitted from the report.

The Economic Outlook

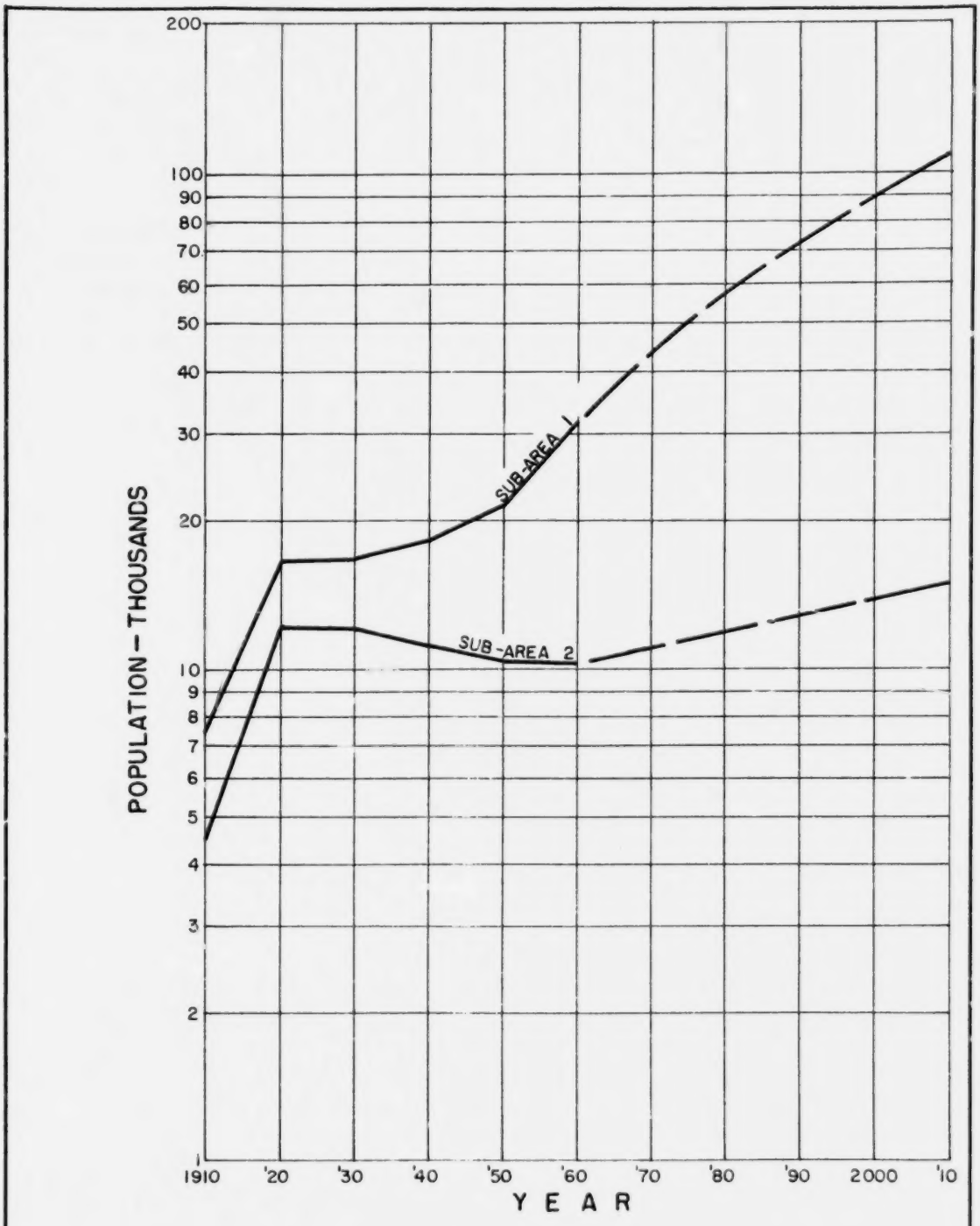
Employment in agriculture is expected to remain at a low level in the future. The increased demand for food and fiber should not produce a corresponding increase in farm employment, since improvement in technology will probably increase productivity per worker. Also, this area would have difficulty competing with other areas, with the tendency toward mass production of many food products in locations best suited to their cultivation.

Accurate estimates of petroleum reserves in the area are difficult to obtain, but no evidence has been found to indicate that a point of serious depletion is being approached. With continued explorations and an increase in secondary recovery operations, it is assumed that extractive industry will hold its own in the future. Petroleum-oriented industry is likewise expected to remain at or near present levels of activity.

The principal changes that can be foreseen are further increases in diversified industry and perhaps a greater proportion of total employment engaged in service industry and related activities. The completion of the barge canal up to Tulsa from the Mississippi River should give added stimulus to industries concerned with durable, heavy goods.

Subarea No. 1

The thriving city of Bartlesville is the home office of two major oil companies. It exhibits all of the factors favorable to a high rate of growth and is the nucleus for the municipal population projected for Subarea No. 1 and shown on Figure 2.



SAND, SKIATOOK, AVANT, & COPAN RESERVOIRS
LOWER VERDIGRIS RIVER SYSTEM

POPULATION PROJECTIONS
SUB-AREAS 1 & 2

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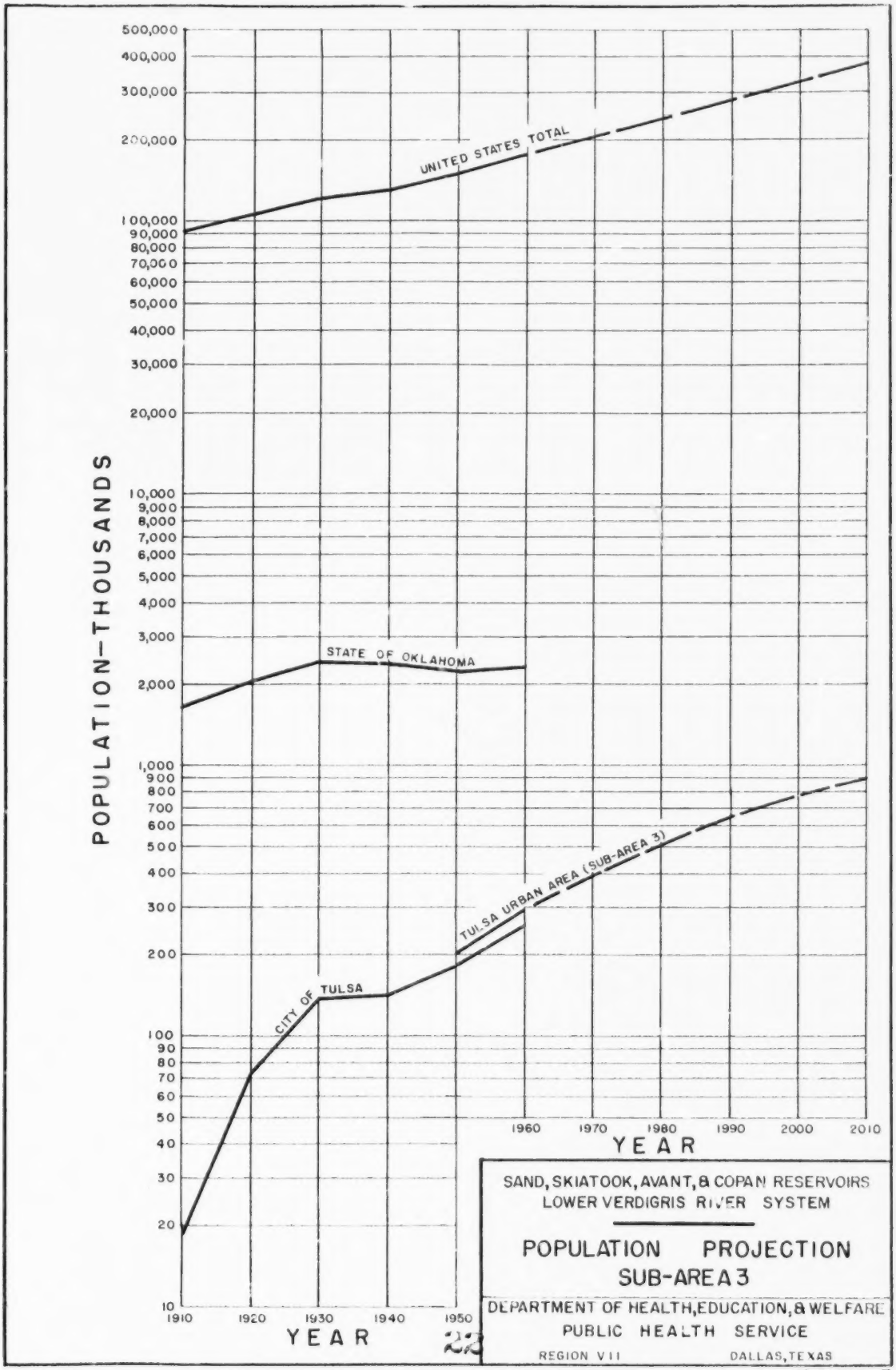
FIGURE 2

Subarea No. 2

This subarea, located between the urban centers of Bartlesville and Tulsa, appears to be suffering the consequences of the national trend toward urbanization. Its towns are too far away from either center to be affected by a spillover of population, yet too close to permit the logical expectation that a third urban center will develop. The static nature of past population history is shown graphically on Figure 2. The projected rate of increase shown on Figure 2 reflects the anticipation of a widening circle of influence from its neighboring larger cities.

Subarea No. 3

Tulsa, the nucleus for Subarea No. 3, is also the metropolitan center for all of northeastern Oklahoma. Although it is somewhat smaller than Oklahoma City, these two might be regarded as the "metropolitan twins" of the State of Oklahoma. The projected growth rate for this subarea, shown on Figure 3, parallels the growth projected for the Oklahoma City area in a concurrent study made by this office.



SAND, SKIATOOK, AVANT, & COPAN RESERVOIRS
LOWER VERDIGRIS RIVER SYSTEM

POPULATION PROJECTION
SUB-AREA 3

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FIGURE 3

V. PROJECTED WATER DEMANDS

Municipal Water

Municipal water use, as defined for the purposes of this report, includes residential, public, and commercial use, plus those industrial uses which can reasonably be reflected in an overall per capita use figure. Examples of the latter are soft-drink bottling works and milk processing plants whose products are consumed mainly by the people residing within the projection area. Projections of municipal water requirements were made by multiplying the projected municipal population by a unit use factor in gallons per capita per day (gpcd).

Available data from municipalities in the Southwest have been analyzed in an attempt to discover the trend of per capita water use, and to correlate this use with some indicator, such as population size group, personal income, price of water, or climate. Such analyses have thus far failed to reveal a usable relationship with any of the customary parameters. Therefore, for the purposes of this study, rather arbitrary values of per capita use, based primarily upon judgment, were adopted. The adopted values for the year 2010 are:

For Subarea Number 1 - 180 gpcd
For Subarea Number 2 - 150 gpcd
For Subarea Number 3 - 190 gpcd

The above numbers represent the quantity of raw water which must be available at the source. They are intended to include distribution system losses, unaccounted-for water, treatment plant attenuation, and evaporation from receiving reservoirs. They do not, however, include losses in transit, if any, or evaporation from source impoundments.

It is intended that the projected values reflect not the average use in all climatic cycles, but the high demand during a critical drouth year, and, further, that they incorporate a factor of safety to insure that future water needs will not be under-estimated. The basic viewpoint is illustrated by the following excerpts from a report, "Future Water Requirements For Municipal Use," recently prepared by the Public Health Service for the Select Committee on National Water Resources, United States Senate. 2/

> "Considerable judgment is ...required in planning for future services, but an important consideration to be kept in mind is that, in developing public water supplies, it is essential that every precaution be taken in the interest of public safety and welfare. For these reasons, it is generally better to overbuild than to underbuild.

"While the trends developed from the Public Health Service inventory of municipal water use indicate a recent leveling off in the per capita use of water ..., prudent judgment suggests the desirability ...of anticipating a possible resumption of the more rapid rate of increase ....

"...it appears that the present 147 gallons per capita per day of /national/ average municipal use could ...conceivably increase to about 185 gallons ...in 1980, and to, perhaps, 225 gallons ...in the year 2000...."

Industrial Water

Total projected water demands have been divided into two components - municipal, as previously described, and industrial. More accurately descriptive names for the two components might be "municipal" and "special." In any case, industrial water use is defined as that which is a function of the size and type of industrial plant and not directly related to the population of the area in which the industry is located. It may be expressed as the number of gallons per unit of product, as gallons-per-employee, or as a ratio of industrial to municipal water.

The necessity for making a separate projection of industrial water will depend on its magnitude in relation to the total water demand. This may vary from a negligible quantity in a large urban area with diversified industry to several times the municipal component when there is a predominance of the so-called "wet" industries. Examples of wet industries are pulp and paper mills (water used for conveyance of the products) and thermal-electric power plants (water used for cooling).

The thermal-electric power plant furnishes a striking example of the possible variation in water use within an industry. The gross intake of water to a power plant using the once-through cooling process may be 150 times the amount used by a plant designed for recirculation.

The following assumptions have been made for projecting industrial water demand in the study area:

(1) Present trends will continue and result in greater diversification of industry.

(2) No serious shortage of water will occur, but economic and engineering considerations will foster conservation practices, such as optimum recirculation of cooling water.

(3) It will be sufficiently accurate to estimate industrial water requirements by assuming a ratio of industrial to projected municipal demand. (Exception has been made

for electric power, for which the projected requirement is based on anticipated plant capacity and the water use rate per kilowatt of capacity.)

Projected Subarea Demands

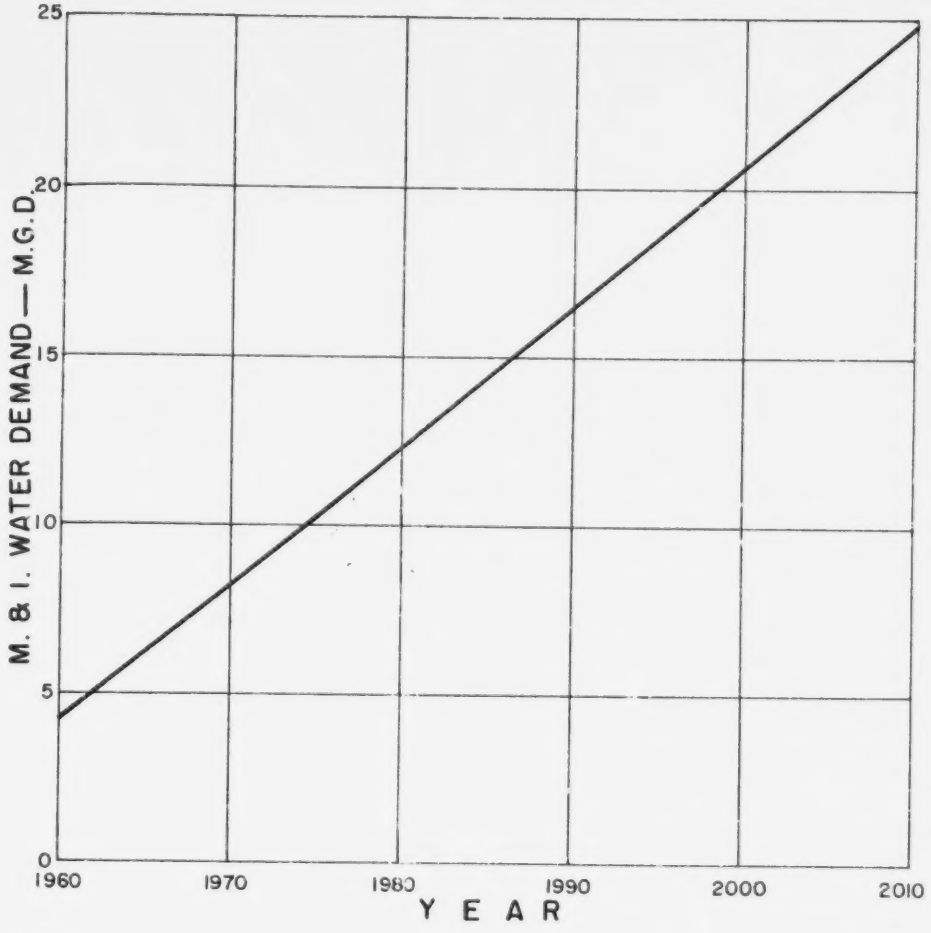
Application of the methodology just described results in the projected water demand for Subarea No. 1 shown on Figure 4. In 1959, the ratio of industrial to municipal use was about 20 per cent. This ratio was increased to 25 per cent for the year 2010. In 2010, therefore, the projected demand is 19.8 mgd for municipal plus 5.0 mgd for industrial, or a total municipal and industrial demand of 24.8 mgd.

In Subarea No. 2, it is projected that the present water use of about 1.9 mgd will increase to about 3.0 mgd.

The curve of projected water demand for Subarea No. 3 is shown on Figure 5. The municipal component of total demand projected for 2010 is 171 mgd. In 1959, industrial use in this subarea was about 38 per cent of municipal. The major part of this use was by two oil refineries. With greater diversification of industry in the future, the ratio of the water use by this "wet" industry to the total demand is expected to decrease. For 2010, the assumed ratio of industrial to municipal is 30 per cent (exclusive of a large electric power plant near Oologah Reservoir). The projected industrial component is, therefore, 51 mgd.

The Oklahoma Public Service Company (the electric utility supplying this region) is building a new thermal-electric plant to take water from Oologah Reservoir. Initial installed capacity of this plant is to be 170,000 kilowatts, with anticipated enlargement to an ultimate capability of one million kilowatts. Officials of the power company estimate that the initial plant will use about 2.8 mgd of water, that is, about 0.017 mgd per 1,000 kilowatts. Applying this factor to the projected ultimate capacity indicates a need for about 17 mgd. (The plant is designed for maximum practicable recirculation.)

The total municipal and industrial water demand in 2010 for Subarea No. 3 is, therefore, 239 mgd.



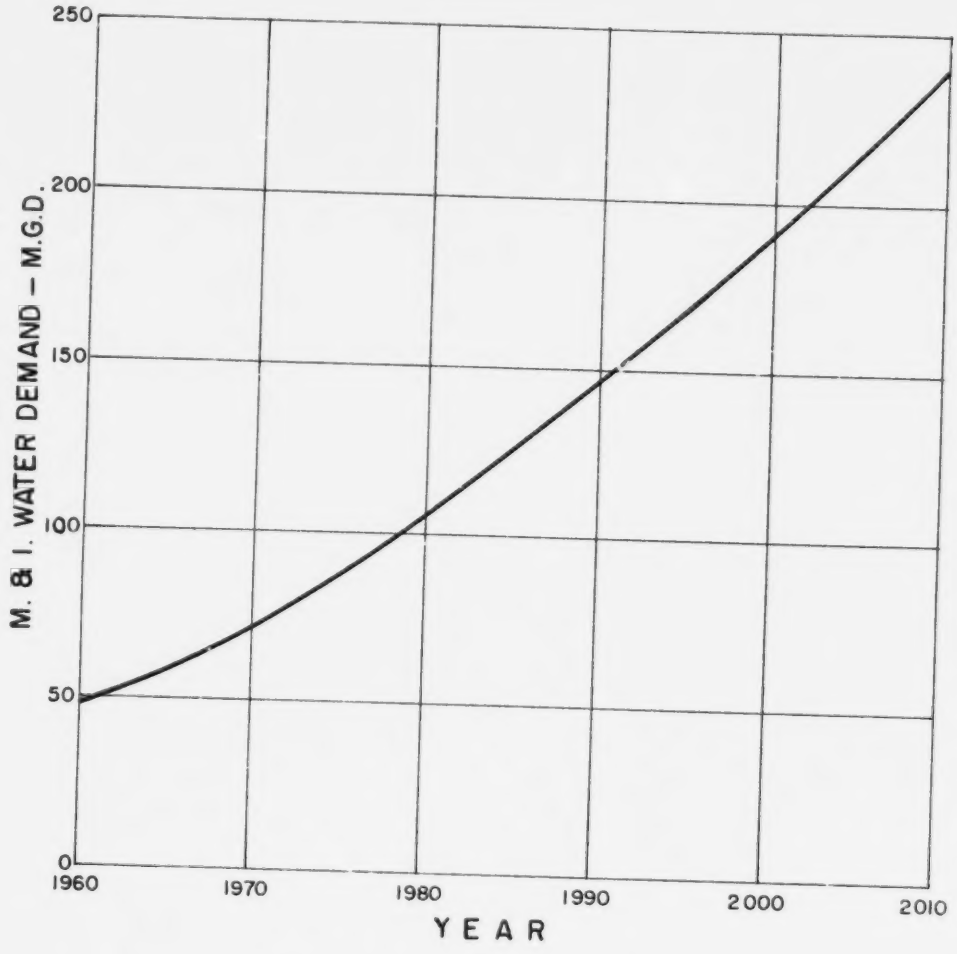
SAND, SKIATOOK, AVANT, & COPAN RESERVOIRS
LOWER VERDIGRIS RIVER SYSTEM

PROJECTED WATER DEMAND

SUB-AREA I

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 4



SAND, SKIATOOK, AVANT, & COPAN RESERVOIRS
LOWER VERDIGRIS RIVER SYSTEM

PROJECTED WATER DEMAND
SUB-AREA 3

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 5

VI. STREAM QUALITY PRESERVATION

Statement of the Problem

Protection of the quality of state waters is primarily the responsibility of state agencies. Stream quality criteria, regulations governing waste discharges, and other pronouncements on the maintenance of water quality within state boundaries, come from these agencies.

The use of water will almost inevitably result in the production of some liquid wastes which, even after a high degree of treatment, will degrade the quality of the receiving stream. Although the final determination and acceptance of stream quality must come from state agencies, it is believed that the criteria and objectives adopted for the purposes of this study are generally acceptable to those agencies.

The first objective of stream pollution control is the protection of public health. The second objective is preservation of the usefulness of the receiving stream. With respect to the second objective, we may divide receiving streams into two classes: those for which there is an indicated need for restoring a quality of water that will permit re-use of the stream as a source of water supply; and those for which there is none foreseen at this time.

Attention is here directed to one facet of a many-sided problem - the question of whether or not storage should be provided in upstream reservoirs for the specific purpose of augmenting low flows to increase the stream's capacity to assimilate wastes.

Alternative Solutions

We believe, first of all, that every producer of wastes (industry or municipality) has an obligation to provide a minimum standard degree of treatment before discharge of waste flow to a stream, regardless of the nature or size of the receiving stream. This minimum standard treatment should accomplish at least four things: (1) neutralization of toxic materials; (2) reasonable destruction of pathogens; (3) essentially complete removal of floating and suspended solids, and (4) a high degree of reduction of biochemical oxygen demand (BOD) of the decomposable organic matter. It is assumed for this study that, within a few years, standard treatment will be universally attained, even though its limits are not now precisely defined. It is further assumed that this treatment will be equivalent to what is now commonly called "secondary" treatment, and that it will remove 90 per cent of the biochemical oxygen demand.

On the other hand, standard treatment will not remove nitrates and phosphates - the nutrients which promote the growth of algae;

nor will it significantly reduce the concentrations of certain persistent organic chemicals and dissolved inorganic materials such as chlorides. Neither conventional treatment nor the natural self-purification processes of streams will successfully deal with the latter constituents of typical municipal wastes.

Another important consideration, where re-use of water is anticipated, is the problem created by what we may call the exotic chemicals. These include insecticides, herbicides, radioactive materials, and others, some part of which will inevitably find its way into sewerage systems and stream courses. Industrial research is today resulting in the introduction of new chemical compounds at a rate which is beyond our present capability even to appraise their long-term effects on human beings, let alone to devise satisfactory treatment processes. For these, the best answer apparent at this time is dispersal, to keep the concentrations low.

From the preceding discussion, it is concluded that the ideal solution is standard treatment of wastes, supplemented by upstream storage that will provide regulated releases to maintain stream flows of sufficient magnitude to finish the job. This conclusion is subject to two reservations - that the provision of storage be economically feasible, and that first priority on available storage may eventually have to be given to supplying municipal and industrial water demands of the immediate area.

The Arkansas River system originates in an arid region and flows into a region of more abundant rainfall and runoff. The study area is intermediate between the two extremes, both geographically and climatically. This study indicates that the potentially available supply of water from the lower Verdigris River system will be ample to meet all needs of the area for the next 50 years. Nevertheless, a time may come when all available storage will be needed to supply first-use demands, with no virgin water left for the dilution of wastes.

It is concluded that, in the long range view, the restoration of all waste waters originating in the study area to a quality high enough for drinking water use, although desirable, may not be practicable. This conclusion leads to consideration of alternative methods for preserving stream quality in all other respects. This objective will be virtually assured by the maintenance of conditions which promote desirable (and discourage undesirable) aquatic life.

We are seeking, therefore, some method of supertreatment (beyond the standard treatment previously defined) which could substitute (in cases where it is acceptable) for the dilution water that would be provided by low-flow augmentation storage. The method which appears most promising at this time is the waste stabilization lagoon. Widespread interest has been aroused in recent years in the possibilities of this method of treatment.

In favor of the use of waste stabilization lagoons for supplementary treatment may be listed the following points:

(1) The estimated cost of construction and operation compares favorably with the costs of the most economical storage reservoirs.

(2) They are readily adaptable to stage construction, thus avoiding the necessity for large initial capital expenditures.

(3) Effluents are high in dissolved oxygen content and low in BOD. (When connected in series with primary and secondary treatment processes, they provide a factor of safety against the release of wastes with high BOD.)

(4) Proponents of lagoons believe that, unlike the other conventional processes, they can effect a substantial reduction in the nutrients of algal growth, i.e., nitrates and phosphates. By promoting an algae-protozoa-insect-fish life growth chain, they avoid the repetitive cycle of algal bloom and decay which may occur downstream from other treatment plants.

(5) When designed on a flow-through basis with currently accepted loading rates, they do not significantly reduce the rate of return flow to the stream.

Disadvantages of lagoons include:

(1) There is a paucity of evidence from actual operation of lagoons restricted to use as the final step in a chain of treatment processes. Historically, they have been used for raw sewage or as secondary treatment. Theory, laboratory experiment, and pilot plant operations support the conviction that the method will be feasible. But there is a need for further field experimentation to confirm the theory and establish design criteria more accurately.

(2) For large urban centers, it may be difficult to obtain the large land areas required, unless the need is foreseen early and taken into account in city planning and zoning. However, to place this fact in proper perspective, it is estimated that the required area of lagoons would be about four-tenths of one per cent of the land area occupied by the city itself.

(3) As previously discussed, the lagoons will not reduce concentrations of chlorides and other dissolved minerals.

Desirable Stream Flows

Estimates have been made of the stream flows required to assimilate residual wastes (after standard treatment) - without reducing the dissolved oxygen content of the combined stream below four parts per million (ppm) at any point in the stream or at any time. With respect to location, there will be two critical points in the study area: one on the Caney River below Bartlesville and the other on the Verdigris River at Tulsa. With respect to time, calculations are made on the basis of a critical drouth year, with water use and waste load conditions as projected for the year 2010. Because of the effect of water temperature on the results, monthly average flows have been estimated for each of the twelve months as well as the annual average.

Waste flows were assumed to be one-half of the average gross intake of municipal and industrial water. Although the gross intake varies seasonally over perhaps a three to one range, investigations of return flows which have been made in this part of the country reveal that the rate of return flow is fairly steady throughout the year. Therefore, steady flow of waste water has been assumed. Strength of the waste was assumed to be 20 ppm of 5 day BOD ($20^{o}C$).

Table 8 gives the results of stream flow estimates for the Caney River at Bartlesville.

At the other (and the major) critical location, the Verdigris River at Tulsa, two additional complications enter the picture. The first of these is that Tulsa's waste collection and disposal is divided - one part going to the Arkansas River and the other part to Bird Creek and thence to the Verdigris River. The drainage divide between the two watersheds cuts the present city of Tulsa approximately in half. A good idea of the direction of future expansion can be gained from a "Comprehensive Plan" prepared in 1960 by the Tulsa Metropolitan Area Planning Commission. 3/ This excellent document includes maps showing proposed zoning and land use, projected to the year 1975. The master plan envisions a continuation of the industrial complex along the Arkansas River and recommends the encouragement of a new industrial development northeast of the present city (on the Verdigris River side of the divide). The best guess, looking 50 years hence, appears to be that waste loads will be divided about equally between the two rivers.

Table 8

Minimum Stream Flows for Waste Assimilation in 2010
Caney River at Bartlesville

Month	Water Temperature °F	Waste Flow (mgd)	Dilution Ratio	Supplementary Stream Flow (mgd)
January	40	12.4	0.05	0.6
February	50	12.4	0.21	2.6
March	55	12.4	0.36	4.5
April	60	12.4	0.52	6.4
May	72	12.4	1.15	14.3
June	86	12.4	2.50	31.0
July	86	12.4	2.50	31.0
August	86	12.4	2.50	31.0
September	79	12.4	1.70	21.1
October	65	12.4	0.75	9.3
November	50	12.4	0.21	2.6
December	40	12.4	0.05	0.6
	Annual Average		1.04	13.0

The second special problem at Tulsa is the question of the effect of canalization of the lower Verdigris River on the stream's waste-assimilative capacity. The low-lift locks and dams will not create conditions comparable to a deep reservoir, but they will result in increased depth and lowered velocity in the stream. By impairing the stream's natural faculty of absorbing oxygen from the air, this will reduce the assimilative capacity of a given flow rate - or, conversely, will increase the supplemental water required to assimilate a given waste load in terms of oxygen demand.

The detrimental effect of canalization will be partly offset by the fact that the navigation plan includes provision of upstream storage to maintain the flows required for navigation operations. As the volume of barge traffic develops, releases from that storage will augment the unregulated stream flow. Even before barge traffic develops, the storage provided for that purpose could still be operated to maintain the same stream flows.

Estimates of waste-assimilation flows have been made for two cases, that is, with and without the navigation dams on the Verdigris River. Table 9 shows both sets of answers. For these calculations, it was assumed that the net effect of the depth-increase and velocity-decrease is to cut in half the reaeration factor of the Streeter-Phelps oxygen balance equation. It must be admitted that this assumption is in the nature of an educated guess. The best solution would be to discharge wastes to a stream which does not have the succession of stepped pools characteristic of an inland navigation project. How-

ever, it must be recognized that the navigation network is being extended to more and more streams; that a typical navigation route is built to (or through) the heavy waste-producing centers which it is intended to serve; and that the problem cannot be avoided by a statement of ideals. There is a need for extensive investigation to define more clearly the corrective measures which should be incorporated in a master water resources plan.

Table 9

Minimum Stream Flows for Waste Assimilation in 2010
Verdigris River at Tulsa

Month	Water Temperature °F	Waste Flow (mgd)	Natural Channel		Navigation Channel	
			Dilution Ratio	Supplementary Stream Flow (mgd)	Dilution Ratio	Supplementary Stream Flow (mgd)
January	40	60	0.05	3.0	0.48	28.8
February	50	60	0.21	12.6	0.86	51.6
March	55	60	0.36	21.6	1.10	66.0
April	60	60	0.52	31.2	1.40	84.0
May	72	60	1.15	69.0	2.50	150.0
June	86	60	2.50	150.0	5.00	300.0
July	86	60	2.50	150.0	5.00	300.0
August	86	60	2.50	150.0	5.00	300.0
September	79	60	1.70	102.0	3.50	210.0
October	65	60	0.75	45.0	1.89	114.0
November	50	60	0.21	12.6	0.86	51.6
December	40	60	0.05	3.0	0.48	28.8
Annual Average			1.04	62.5	2.34	140.4

VII. VALUE OF STORAGE

Evaluation Method

The underlying philosophy of the method adopted for monetary evaluation in this report is stated by the following quotation from the Corps of Engineers manual EM 1165-2-105, dated September 7, 1960. 4/

> "The benefits from municipal and industrial water supply storage result from improvements in conditions of water use, largely in regard to quantity and dependability, quality, and physical convenience. In basic concept, the limiting values of such improvements are the maximum amounts prudent users would be willing to pay for the water supply storage components of municipal and industrial water supplies, assuming that decision would be made on the basis of a broad public viewpoint rather than a regional or local viewpoint. However, because of the complex objective and subjective considerations involved in the establishment of these maximum amounts, precise measurement of benefits on this basis frequently is difficult, if not impossible. Pending improvements in evaluation techniques, alternative costs comprise a conservative and the most generally acceptable basis for measurement of the benefits from municipal and industrial water supply storage."

The dominant single element in the future water supply picture of the study area is Oologah Reservoir. With an ultimate potential for conservation storage of over half a million acre-feet on a stream whose average flow is nearly four thousand cubic feet per second, it overshadows the four tributary reservoirs which are the subject of study in this report. Nevertheless, these small reservoirs offer advantages, in closer proximity to localized demand centers, and in possible contribution to total water needs if proved to be economical in comparison with larger sources.

Estimated benefits from storage are presented below for each of the four reservoirs for the firm yields as currently formulated, and in consideration of possible use for both water supply (municipal and industrial) and stream quality preservation. Alternative construction costs were converted to an equivalent series of annual payments, using a 50-year economically useful life and a non-Federal interest rate of 4 per cent. Estimated annual costs of operation and maintenance were then added to give total annual benefits.

Sand Reservoir

This project would be strategically located with respect to the Bartlesville demand center, and storage would have future value after the demand increases beyond the capability of the present source in Hulah Reservoir. Two alternatives to the Sand multiple-purpose project were considered. (1) a single-purpose dam at the project site, and (2) Oologah Reservoir with adjustment for difference in transmission cost. The first (a single-purpose dam at the site) was found to be the best alternative.

Cost estimates for alternative reservoirs have been furnished by the Tulsa District Office, Corps of Engineers. It is recognized that these cost figures are preliminary in nature, but they are considered to be sufficiently accurate for the purpose of estimating benefits.

The estimated annual benefit from storage in Sand Reservoir to yield 7.8 mgd is $161,500. This value would accrue from and after the projected date of first need, 1975. This and subsequent values have been adjusted to a common time base, by discounting at 4 per cent, compounded annually, from date of first need back to 1965 - assumed earliest date of construction. The adjusted 1965 value for Sand Reservoir is accordingly $109,000 per year, which corresponds to 3.8 cents per thousand gallons at full utilization.

Copan Reservoir

For the proposed yield of 4.0 mgd at this site, the most reasonable alternative source was determined to be Oologah Reservoir. Cost of storage at Oologah was taken to be a pro rata share of the estimated cost of a single-purpose dam at that site which would have a water-supply storage volume of 260,000 acre-feet and yield 154 mgd. To this cost was added the estimated cost of transporting Oologah water to the Bartlesville demand center.

The resultant value of storage in Copan Reservoir is $115,000 per year - this benefit to begin in about the year 1990. From that date until about 1995 storage in Copan would have an interim use for low-flow augmentation, after which it would be needed for water supply. In this particular case, the interim use of storage for maintaining stream flow is considered to have value equal to that of its ultimate use as water supply, since the dilution water so provided can help to restore the quality of return flows in the local area for downstream use of the combined total. Discounting from date of first utilization (1990), the 1965 value of storage is $43,100 per year, or 3.0 cents per thousand gallons at full utilization.

Avant Reservoir

The indications of potential demand for water supply storage in this reservoir are not nearly so clear-cut as in the preceding cases. Present water demand in the local area is distributed among half a dozen small towns, the largest of which is Pawhuska (1960 population, 5,300). For the purpose of evaluation, it has been assumed that 2.0 mgd of the projected total municipal and industrial demand of 3.0 mgd might be supplied from Avant Reservoir. The alternative source used for evaluation was the Hulah Reservoir, from a portion of the as yet unallocated conservation storage. Adjustment for transmission cost was made on the assumption that the point of delivery of water would be Pawhuska.

On the foregoing basis, the estimated value of storage in Avant for a yield of 2.0 mgd is $85,400 per year or 11.7 cents per thousand gallons at full utilization. It is considered that a reliable source of supply would have value at whatever date it becomes available, and hence the value has not been discounted in this case. Noteworthy is the fact that the alternative unit cost of water in this case is relatively high and may be encroaching on the ceiling of our "prudent user's" willingness to pay for reliability. Caution is indicated, therefore, in any consideration of extrapolation to higher yields by the use of this unit value.

Skiatook Reservoir

There is not a clearly indicated need for storage in this reservoir, except as it might possibly contribute a small share toward meeting the overall needs of the area, either for water supply or for helping to preserve stream quality. The site offers no significant advantages when compared to the two major potential sources - the Grand River and its tributaries (present source) and the Verdigris River.

For municipal and industrial water supply, the estimated value of storage in Skiatook Reservoir is 0.87 cents per thousand gallons of firm yield or $12,700 a year for a yield 4.0 mgd. This value is based on the pro rata share of alternative cost of storage in Oologah Reservoir (as previously discussed for Copan Reservoir).

For stream quality preservation, the estimated value of storage in Skiatook Reservoir is 0.235 cents per thousand gallons of yield, that is, $860 per year per mgd of stream flow maintained. This estimate is based on the alternative of lagoons for the supplementary degree of waste treatment that would be required in the absence of assured stream flows. Details of the computation procedure for this alternative are given in the Appendix.

APPENDIX

EXHIBIT A-1

CALCULATIONS FOR ALTERNATIVE LAGOONS

I. Design Criteria and Assumptions:

1. Lagoon system to be expandable by parallel units, each unit to consist of two series cells, sized to receive 10 mgd of waste flow.

2. BOD (5 day, 20°C.) of influent: 20 ppm.

3. Loading rate: 30 pounds of 5 day BOD per acre.

4. Depth of water: 5 feet.

5. Size: $\frac{10\ (8.33)\ 20}{30}$ = 55.6 acres (water surface).

6. Land required: 90 acres per unit (allowing for buffer zone).

7. Detention time: $\frac{55.6\ (5)\ (43{,}560)\ 7.5}{10{,}000{,}000}$ = 9.1 days (without allowance for evaporation).

8. Reduction of flow -

Evaporation rate: 6 in./mo.
Rainfall (drouth): 1 in./mo.
Net: Evaporation minus rainfall: 5 in./mo.

$$\frac{5\ (55.6)\ 43{,}560\ (7.5)}{12\qquad\quad(30)} = 0.25 \text{ mgd.}$$

Ratio: $\frac{\text{Outflow}}{\text{Inflow}} = \frac{9.75}{10}$ = 97.5 per cent.

II. Estimated Cost:

1. Construction -

Land - 90 acres @ $500	$45,000
Clearing, grubbing, rolling, and sealing - 60 acres @ $150	9,000
Dikes, 37,000 cu. yd. @ $0.50	18,500
Fence, 3,200 lin. ft. @ $0.50	1,600
Pipes, values and appurtenances, Lump Sum	5,000
Subtotal	$79,100
Administration, engineering, and contingencies	15,900
TOTAL	$95,000

2. Annual Costs -

Fixed: $95,000 (0.0466)	$ 4,430
Operation and maintenance, Lump Sum	4,530
TOTAL ANNUAL COST	$ 8,960

3. Comparison with dilution flow -
(10 mgd of waste flow requires 10.4 mgd of supplementary stream flow in natural channel in the absence of lagoons).

$$\frac{\$8,960}{10.4\ (1,000)\ 365} = \$0.00235 \text{ per 1,000 gallons of yield from storage.}$$

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